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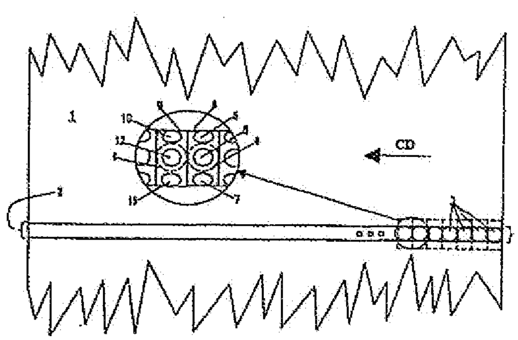

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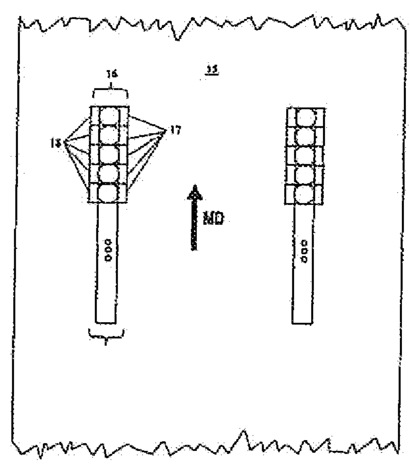

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(57) Abstract

A non-scanning sheet monitoring system is described which uses a plurality of compact, low part count sensor units (5) to measure a plurality of wavelengths from a plurality of measurement locations (3). Each sensor unit includes a plurality of radiation detectors (6, 7), each detector used to detect a different radiation wavelength. A source of radiation (8) may be associated with each sensor unit, a single source of radiation (8) may be used to illuminate the sheet for multiple sensor units, or passive radiation may be used. The sensor units may be arranged along a single line, or may be staggered in position.

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NON-SCANNING, ON-LINE MULTIPLE WAVELENGTH SHEET MONITORING SYSTEM

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates generally to systems for monitoring characteristics of a moving sheet of material. More particularly, the invention relates to a method of providing non-scanning, multi-characteristic monitoring of a line or strip of a sheet of material.

DESCRIPTION OF THE PRIOR ART

With the advent of recent technology advances in sensing hardware, continuous sheet industries, such as the paper industry, have come to expect more feature-rich, and higher resolution sheet monitoring systems. In part, this has led to recent development of a number of non-scanning sheet monitoring and controlling systems which may soon replace the current population of scanning systems in mills and plants.

Non-scanning systems provide not only more complete data about the moving sheet, they also provide a desirable separation between MD and CD. Scanning systems inherently couple CD and MD variations, although there are a number of ways to reduce or eliminate the coupling. As one of skill in the art will be aware, attempts to control a moving sheet process, without knowing whether a disturbance is in the CD or MD direction, is a frustrating and costly problem.

Non-scanning systems may consist of a row of sensors nearly equal in size to the region of measurement, or may be smaller than the region of measurement and rely on optics and separation from the sheet to monitor the entire region of measurement (such as with a CCD camera). Systems smaller than the region of measurement suffer from a weak radiation signal --caused by foreign substances in the measurement path-- among other difficulties. For example, steam between the paper and the sensor device can absorb large amounts of sensor radiation before it reaches the detectors, distorting sensor output.

For non-scanning systems which physically extend across the entire width of the region of measurement, the sensor units should be as compact as possible to save valuable sheet forming machine space. One way to reduce the size and bulk of the systems embedded in the sheet forming machine, is to monitor multiple wavelengths

with a single sensor unit. The multiple wavelengths may be used to provide multiple types of sheet characteristic data with a single device, thus conserving on-machine space.

Several inventors have previously recognized that multiple wavelengths can be measured with a single sensor unit. For example, United States Patent 3,965,356 issued to Howarth and assigned to Measurex Corporation describes an apparatus for measuring two or more radiation wavelengths with a single device. The described device however, is used in a scanning environment, and is not suited for a non-scanning arrangement due to its size and complexity. Another patent, 4,801,809 issued to Burk et al., and assigned to Process Automation Business, describes multiple wavelength measurement for a non-scanning system, but actually takes measurements of different wavelengths from adjacent measurement locations, rather than taking measurements for two wavelengths from the same measurement location on the sheet surface. The Burk system therefore has a greater degree of MD/CD coupling which the manufacturer would like to eliminate. Further, the Burk system includes expensive and complicated detector arrays, diffraction devices and imaging components which increase the cost and complexity of the system.

SUMMARY OF THE INVENTION

The present invention addresses these difficulties by providing a non-scanning sheet monitoring system which uses a plurality of compact, low part count sensor units arranged to measure a plurality of wavelengths from a line or strip of measurement locations on a sheet or web or material. Each sensor unit includes a plurality of radiation detectors; each detector is used to detect a different radiation wavelength or band of wavelengths. All detectors in a sensor unit detect radiation from a common measurement location (i.e. performing "same spot" measurements). A source of radiation may be associated with each sensor unit, a single source of radiation may be used to illuminate the sheet for multiple sensor units (such as via a fiber-optic cable), or passive radiation may be used (i.e. no dedicated source of radiation). The sensor units may be arranged along a common line in either the MD or CD or diagonal to both, or may be staggered in position. The sensor units may or may not take measurements simultaneously. If measurements are not simultaneous, measurements along a common line may still be achieved by sequencing measurement times for each sensor unit, or group of sensor units in a common line, based on the sensor units' location.

In fact, the Applicants'' system could provide essentially unlimited types of measurements to be taken from the same spot on the web or sheet by staggering measurements from a row of sensor units arranged in an MD line.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1a shows one embodiment of the Applicants'' non-scanning system, applied in the CD.

Figure 1b shows another embodiment of the Applicants'' non-scanning system, applied in the MD.

Figure 2a shows an embodiment of the Applicants'' sensor unit in a cross-sectional side view.

Figure 2b shows the embodiment of Figure 2a as viewed from above.

Figure 2c shows an embodiment of the Applicants'' sensor unit comprising six radiation detectors and utilizing an external source of radiation (not shown).

Figure 2d shows an embodiment of the Applicants'' sensor unit comprising eight radiation detectors.

Figure 2e shows an embodiment of the Applicants'' sensor unit having eight radiation detectors, arranged in two separate circumferences of four radiation detectors each, around a central light source.

Figure 3 shows another embodiment of the Applicants'' sensor unit utilizing a central source of radiation, rather than individual sources of radiation for each sensor unit.

Figure 4a shows one configuration of the radiation detectors in each sensor unit.

Figure 4b shows a second configuration of the radiation detectors in each sensor unit.

Figure 4c shows another configuration of the radiation detectors in each sensor unit.

Figure 5a shows a simple non-staggered arrangement of the sensor units capable of measuring simultaneously along a common line.

Figure 5b shows a side view of the sensor unit arrangement shown in Figure 5a.

Figure 6a shows a second possible arrangement of the sensor units which utilizes a staggered arrangement, and smaller measurement locations, suitable for non-simultaneous sensor unit measurements.

Figure 6b shows a side view of the sensor unit arrangement shown in Figure 6a.

Figure 6c - 6e shows movement of a cross-direction line through a measurement region for a system similar to that shown in Figures 6a and 6b.

Figure 6f shows an arrangement of Sensor units in the MD used to take same spot measurements with all or a multiple number of the sensor units in the system.

Figure 7a shows a staggered sensor unit arrangement, which may be used to compensate for slow radiation detectors.

Figure 7b shows a side view of the sensor unit arrangement shown in Figure 7a.

Figure 8a shows a staggered sensor unit arrangement, using tilted sensor units, so that simultaneous measurement along a common line is possible with staggered sensor units.

Figure 8b shows a side view of the sensor unit arrangement shown in Figure 8a.

Figure 9a show a sensor unit arrangement utilizing reflective coatings mounted on the underside of the sensor units to enhance sensor unit performance.

Figure 9b shows a side view of the sensor unit arrangement shown in Figure 9a.

Figure 9c shows a sensor unit arrangement utilizing reflective coatings in conjunction with transmissive radiation detector measurements.

Figure 10 shows a sensor unit configuration utilizing a dithering mechanism to improve sheet coverage.

DETAILED DESCRIPTION

Figure 1a shows one embodiment of the Applicants'' inventive system. In the Figure, a sheet or web material 1, such as paper, plastic, fabric, metal or glass, moves forward through the sheet forming machine (i.e. up or forward in the Figure). For reference, machine direction (MD) is defined as forward, and cross-direction (CD) is defined as left to right along the paper.

A measurement region 2, traverses a cross-direction strip or line of the sheet. The measurement region defines a series of measurement locations 3 (ie. spots) at which measurements of sheet characteristics are taken. The measurement locations, and thus the sensor units, may or may not extend across the entire sheet width. In Figure 1a, only the first few measurement locations are shown.

Adjacent each measurement location is a sensor unit which measures changes in the sheet at the associated adjacent measurement location, typically by examining scattered light from the measurement location, but specular reflection may also be used (such as for gloss measurements). The blow-up in Figure 1a shows one possible embodiment of the sensor units. A first sensor unit 5, contains first and second

radiation detectors 6 and 7, respectively, and first source of radiation 8. Similarly, a second sensor unit 9, contains third and fourth radiation detectors, 10 and 11, respectively, and a second source of radiation 12.

Figure 1b shows another embodiment of the Applicants'' invention, applied for collecting MD data about web or sheet 15, or for collecting large amounts of data from a single point. In the Figure, a measurement region 16, traverses a machine-direction line or strip of the sheet. Measurement region 16 defines a series of measurement locations or spots 17 at which measurements of sheet characteristics are taken. Data at each measurement location is taken by sensor units 18, having a similar configuration and operation to that of the sensor units shown and described in Figure 1a.

The number of measurement locations used in embodiment of Figure 1b could be set by any number of factors. For example, measurement region 16 could be made the same length as the sheet width, to allow correlation with a CD measurement system, such as the one shown in Figure 1a. Alternately, the measurement region could be long enough to capture a full period of certain types of periodic MD sheet disturbances. As a further possibility, multiple sensor units could take data from the same spot on the web or sheet, by staggering sensor unit measurements. In this type of system, the number of sensor units --and thus the length of the measurement region-- would depend on the number and type of datum desired, and the number of type of datum an individual sensor unit could measure.

As a preferred embodiment, numerous separate sensor units have been chosen by the Applicants', rather than a single-piece measurement system. This design allows easy configuration of the system for various sheet sizes and applications. However, single-piece measurement systems may be preferable in some circumstances. For example, some standard sheet size systems may be produced for less cost with single-piece measurement systems. Single-piece measurement systems may also be preferable for smaller sheet widths, such as in the plastics industry, or for MD or single spot measurement systems where the length of the measurement system is not dependent on or controlled by the sheet size.

One or more of the Applicants'' measurement systems may be used in a single sheet plant or mill. For example in a paper mill, the Applicants'' system may be placed before or after the coating section, breaker stack, wet press section, or other sections, as data about the sheet is needed.

In operation, the source of radiation for each sensor unit impinges on the

appropriate measurement location (i.e. spot) adjacent that sensor unit. The radiation detectors for the sensor unit each monitor the measurement location for a different radiation wavelength or wavelength band. Typically, scattered, rather than specular reflection is examined by the radiation detectors, although specular reflection may also be utilized. A microcontroller or other device and associated components calculate, format and/or normalize data from the sensor units. This information may then be used to produce any number of sheet characteristic values, such a moisture, basis weight, gloss, thickness, $CaCO_3$ content, cellulose, coat weight, latex, clay, silicone, sheet temperature, etc. either alone or in conjunction with other radiation wavelength data, other sensor unit data, and/or other external data. The sheet may be held in place with a sheet stabilization mechanism to enhance measurement accuracy of the sensor units.

For a substantial number of sheet measurements in the paper industry, the desired range of radiation for measurements is in the 1.9 to 2.2μm range. In this region, one wavelength is chosen as a measured wavelength, and a second wavelength is chosen as a reference. As one of skill in the art will understand, the measured wavelength may be called and will be referred to as the measure wavelength. To determine a sheet property measurement, the reference wavelength intensity is compared to the measured wavelength intensity. Then, relying on the fact that the measured wavelength is more sensitive to the sheet property being measured than the reference wavelength, a determination of the desired sheet property is calculated. For example, for moisture, 1.9μm can be used as the measured frequency, and 1.8μm as the reference frequency.

One possible measurement technique is now described. During calibration, the sensor units are exposed to a family of known conditions for the type of measurement to be taken. The ratio of the reference and measure wavelength in this family of known conditions is used to produce coefficients of an equation which describes the sheet conditions for any value of the reference to measure wavelength ratio. During system operation, the measure value versus reference value ratio is used in the equation created during calibration to produce a sensor unit output representing the sheet condition.

Of course, measurements outside the 1.9 - 2.2μm band may also be useful. For example, 3.9μm is an effective measurement wavelength for Calcium Carbonate, with 3.8μm being used as a reference wavelength. Other types of measurements may utilize wide bands of radiation, and only a single detector (i.e. no reference wavelength is measured). For example, gloss, which is measured with green light utilizes the band of

radiation between 400 and 600nm, and relies on specular reflection.

A cross-sectional side view of a further sensor unit, capable of measuring four wavelengths of radiation rather than two is shown in Figure 2a, with a top view of the same device shown in Figure 2b. In the Figures, a sensor unit body 20 houses four radiation detectors 21 - 24 which lie in circumference around a center cavity. The center cavity may contain a lens or other focusing device, may be empty, or may contain a source of radiation. In the Figure, the cavity is shown containing a lens 25, which is used to manipulate radiation from source of radiation 26, situated above the lens. For systems using scattered radiation, lens 25 typically focuses the radiation to a small spot to reduce the chance of specular radiation reaching the radiation detectors. A further lens or reflecting member 27 may lie below lens 25 to focus radiation from source of radiation 26, or to reflect back radiation reflected from the surface of the sheet. Lenses and other radiation manipulation components can add cost and complexity to sensor unit design. To avoid this the sensor units may be placed closer to the sheet, since the closer to the sheet the sensor unit is located, the smaller the number of lenses and other radiation manipulation components are needed. In some cases lenses and other components are unavoidable however. For example, if the sensor units are placed too close the sheet, random specular reflection becomes a problem. If the sensor units are moved outside the region where random specular reflection is a problem, the need for lenses --to produce/gather enough light on the sheet surface-- increases.

Figures 2c through 2e show sensor units utilizing more than four radiation detectors. In Figures 2c and 2d, the radiation detectors are arranged in a simple circumference. In figure 2e, a second set of radiation detectors is arranged in a second wider circumference. In either case the extra sensors could provide separate measurements or serve as a reference to other radiation detectors in the sensor unit.

Radiation detectors 21 - 24 are comprised of a radiation sensing means, such as a bolometer, or other radiation sensitive device, and a filter, such as an interference filter. The interference filter allows only the desired radiation wavelength or band of radiation wavelengths to reach the radiation sensing means or alternately, using one or more filters, a plurality of spaced wavelengths or wavelength bands may be monitored with a single radiation detector. The filter may be a fixed type, or some form of variable filter, such as an acoustically tuned optical filter (ATOF). Use of an ATOF-type filter increases the versatility of the system since the same system may be modified

and adjusted to measure different types of properties without any hardware changes. If the filter chosen can be switched from one band to another fast enough, the changes may be made on-line to provided alternately two or more types of measurements of the sheet. Of course, the ATOF filter may complicate the sensor unit housing somewhat depending on the required supporting hardware, and this may be a factor in the chosen design. As indicated by the (1 through (4 symbols in the Figure, each radiation detector senses a different radiation wavelength or wavelength band, although, two or more radiation detectors may sense a common radiation wavelength for special purposes, such as fiber orientation.

In a slightly different embodiment of the Applicants'' invention, the radiation detectors may be located outside the sensor unit, and using fiber optic cables, radiation may be fed to externally mounted detectors. This can substantially reduce the bulk of the sensor units in the area of the moving sheet, but could require costly fiber optic cable, depending on the wavelengths the designer wishes to measure.

The source of radiation may be any bulb or other radiation means which provides radiation in all the wavelengths which the detectors are designed to detect. In fact, just about any simple type of light bulb would be sufficient for this purpose, assuming the bulb maintains a relatively constant intensity in the measured radiation wavelength ranges. Typically, most types of detectors use intensity of the received source of radiation to create measurement signals. Thus, a source of radiation having an unstable radiation intensity might cause changes in sheet characteristics to be confused with fluctuations in the source of radiation's intensity. A reference of the radiation's intensity is typically used to improve the accuracy of the sensor unit measurements.

While the embodiment of Figure 2a utilizes an individual source of radiation for the sensor unit shown, a single source of radiation may be used for more than one sensor unit, with a radiation distribution means used to distribute radiation from the single source to the more than one sensor units. In Figure 3, for example, sensor unit 30, receives radiation from a central source of radiation 31, via fiber optic cable 32. This same central source of radiation may be used to provide radiation to all or some smaller number than all the sensor units in the cross-direction strip.

Distribution of radiation from the source of radiation to the radiation detectors may be aided with the addition of specular and non-specular reflective coatings mounted on the underside of the sensor units. These coatings spread radiation from the source of radiation to more locations on the sheet, and allow more effective

measurement of very thin and very thick sheet materials. The latter is the result of multiple interactions of the radiation source's radiation with the sheet. A more detailed description of the use of these coatings is described in U.S. Patent 3,793,524, issued to Howarth and U.S. Patent 5,276,327 issued to Bossen, et al., both assigned to Measurex Corp, the content of which is hereby incorporated by reference.

Several other configurations for the source of radiation are suitable to the Applicants'' invention and are worth mentioning here. The source of radiation may be mounted externally to the sensor units, a supplemental source of radiation may augment the radiation provided by a centrally located source of radiation, or passive sources of radiation --no dedicated source of radiation, used to measure sheet temperature-- or transmitted sources of radiation --radiation from the opposite side of the sheet from the sensor unit-- may be used. The sources, regardless of location, may be dedicated one to a sensor unit, may shine on the entire length of the cross-direction line, or a source of radiation may be used for a small group of sensor units. Typically, the choice of a source will depend on how easy it is to control radiation in a given design environment, the sensitivity of the detectors, the type of measurement to be taken, and other factors. More than one type of radiation source may be utilized as well, if, for example, one type of desired measurement requires transmitted radiation, and one reflected radiation.

As indicated earlier, many of the most common property measurements in the paper market may be performed using scattered radiation. This may be accomplished with either a transmissive or reflective light source, although the reflective light source is preferred as it keeps all sensor unit components on the same side of the sheet, and reduces some alignment complications. Although notably, basis weight is preferably a transmissive measurement, and gloss is strictly a specular reflective measurement.

The source of radiation may either be on constantly, or the source of radiation may be strobed to operate only when its associated sensor unit is measuring the surface of the sheet. If the source of radiation is constantly on, heat considerations and stray radiation from one sensor unit effecting another sensor unit may have to be addressed in the design. Heating may be controlled with some form of heat sink , fan, or air purge. Stray radiation may be controlled by restricting the radiation detector opening in the sensor unit so that only radiation within the desired incident radiation direction may reach the radiation detector. If the source of radiation is timed to only be on when the radiation detectors are making measurements, heat and stray radiation problems are reduced, but the electronic requirements for this type of system would increase. The

timed source of radiation would also reduce light bulb life, if power for the bulb is simply cycled on and off. As an alternative, a mechanical chopper could be used. Each of these factors and options would be weighed in determining the most effective design for a particular application.

As shown in Figures 2a, and 3, the radiation detectors are slanted inward to receive radiation from the proper portion of the sheet surface. The slanting allows a larger common measurement location to be shared by all radiation detectors in the sensor unit, at a reduced distance between the sheet and the sensor units. Angled radiation detectors also allow increased distance between the radiation detectors and the source of radiation. This reduces the possibility that specular radiation from the source of radiation will reach the radiation detector. As indicated, the described embodiment is useful for scattered-light measurements, which are easier accomplished without the complication of specular light in the radiation detector signals.

The choice of orientation for the radiation detectors, relative to the sheet and the source of radiation is effected by several considerations. First, to receive the strongest signal from the sheet with the smallest chance of specular radiation reaching the radiation detectors or scattered light from other sensor units at the wrong angles, the sensor unit should be as close to the sheet as possible, without interfering with, or being contacted by the sheet. In the Applicants'' preferred embodiment, this distance is between one-half and one inch. Second, when using interference filters to attenuate unwanted frequencies of radiation, only radiation passing within approximately 10° - 12° of incident from the surface of the interference filter is usually recommended to receive the band of frequencies for which the filter is rated. Outside this range of incidence, the interference filter will allow wavelengths of radiation through other than those desired to be detected. Typically, radiation from the measurement location should therefore scatter from the sheet so that it strikes the interference filter in the specified range of angles and radiation from other angles should be blocked. Thirdly, when more than two wavelengths or wavelength bands are to be measured by the same sensor unit (i.e. there are three or more radiation detectors in the sensor unit) the size of the measurement location relative to the width of the sensor unit may become important.

The interrelation of the above factors may be examined with the aid of Figures 4a - 4c. In each of the Figures, the solid lines emanating from the lower surface of sensor units 40 and 41 represent the maximum desirable incident radiation angle for the chosen interference filter. The shaded polygon in each Figure represents the region of

the sheet surface on which both sensor units will take measurements within the range of desired incident radiation angles (.i.e. same-spot measurement). For most sensor measurements (gloss being the noted exception), the radiation source will be focused on a spot small enough so that specular radiation from the source of radiation will not reach the radiation detectors. The size of the spot, and the spacing between the radiation detectors and the source of radiation should be adjusted to allow for some amount of pass-line variation (i.e. sheet bounce, flutter or drift) which might produce specular radiation at larger distances from the spot center than expected. Darker horizontal black lines, such as those labeled 42 and 43, represent possible measurement locations for the chosen sensor unit configuration. The edges of each measurement location are ideally bounded by the region in which both radiation detectors take radiation measurements within the desired incident radiation angles. To prevent radiation from undesirable angles from reaching the radiation detector, the radiation detectors are shielded or recessed into the sensor unit body.

In Figure 4a, radiation detectors 40 and 41 have been angled --with respect to the perpendicular to the sheet being measured-- so that the measurement location can be wide enough to span the width of the sensor unit. In the figure, vertical lines 42 and 43 represent the edges of the sensor unit. A possible measurement location as wide as the sensor unit is labeled as 44. Central source or radiation 46 could provide specular radiation to the system or scattered radiation sources could be placed just outside each radiation detector. It is noted that the chosen angle for the radiation detectors, relative to the sheet surface, makes the possible range of the measurement locations (the shaded triangle) unbounded as the sheet moves farther away from the sensor units. That is, the sensor unit may take as wide a measurement location as desired, by moving the sensor unit farther away from the sheet. Of course, the disadvantage of increasing the distance between the sheet and the sensor unit is threefold. First, increasing the measurement location size decreases resolution. The resolution of the sensor unit is generally limited to the measurement location size. Second, it allows more opportunity for stray radiation to enter the radiation detectors. Third, the signal received from the source of radiation will continue to get weaker the farther the sensor units get from the sheet. To some extent, the spacing between the sensor unit and the sheet may be reduced by decreasing the spacing between the radiation detectors.

One disadvantage of the system of Figure 4a, is that the measurement location varies in size with movement of the sheet. For example, if the sheet bounces from

measurement location 43, to measurement location 42, a substantially smaller portion of the sheet surface is measured, complicating evaluation of the radiation detector signals, and omitting possible information about selected portions of the sheet which may not be examined by another sensor unit. Compared to the other systems described below, however, the system of Figure 4a may be the best choice for a design, if cost reduction and reduced sensor unit size are key considerations, since the system of Figure 4a maximizes hardware use relative to the amount of the sheet the sensor unit measures, and minimizes the amount of on-machine real estate.

In the system of Fig 4b, the radiation detectors have been angled to provide a band of measurement locations which are the same size. For example, measurement locations 47 and 48 shown in Figure 4b cover the same amount of surface on the sheet. Thus, even if the sheet bounces from one measurement location to another, the same size region of the sheet will be measured. Unfortunately, placement of the radiation detectors in the configuration of Figure 4b makes it more difficult for a single sensor unit to individually measure a portion of the sheet as wide as the sensor unit. As will be described later however, staggered sensor units may be used to measure the portions of the sheet missed by a first sensor unit. In the configuration of Figure 4b, a transmissive source of radiation 49 (i.e. mounted in the sheet guide) is shown providing light to the sheet, although another type of source may also be used.

In Figure 4c, the radiation detectors have been angled substantially to reduce the distance between the sensor units and the sheet surface. This configuration of the radiation detectors further reduces the size of the measurement location relative to the width of the sensor unit. A central source of radiation is used to illuminate the sheet in Figure 4c. As with the configuration of Figure 4a, the measurement location size will change with the position of the sheet. Further, the shape of the region of possible measurement locations is bounded (i.e. it decreases to zero some distance from the sensor unit). Despite these drawbacks, this system may be preferable if it is critical for the designer to place the sensor units as close as possible to the sheet. For example, if transmitted radiation is being measured, the radiation passing through the sheet may be very weak, requiring the sensor units be very close to the sheet to maximize this weak signal. This design also simplifies the radiation source placement for a system measuring scattered radiation.

Figure 5a shows a top view of the simplest arrangement of sensor units for examination of a desired region of measurement on the sheet. Figure 5b shows the

same system in end view. In the Figure, each cross-shaped member, such as indicated by numbers 50 and 51, represents a sensor unit. The circle overlaying each sensor unit, such as the one labeled 52 and superimposed on sensor unit 50, represents the measurement location for that sensor unit. Each of four radiation detectors, located at each end of each cross-shaped member, measures a different wavelength from the measurement location, such as shown in Figure 2b. In Figure 5a, this is indicated by the λ_1 through λ_4 symbols appearing inside each measurement location.

In Figures 5a and 5b, the measurement location for each sensor unit is as wide as the sensor unit. Thus, to measure the entire surface in the measurement region would only require a single row of sensor units. In fact, by increasing the spacing between the sensor units and the sheet, the measurement locations may be made to overlap somewhat. This may be desirable, for example, to prevent misalignment or sheet fluctuations from causing gaps in the line of data. For maximum data collection, the system of Figure 5a is the preferred sensor unit arrangement for sensor units like those of Figure 4a, but not for sensor units configurations like those shown in Figure 4b and 4c. The configurations of Figures 4b and 4c do not have measurement locations as wide as the sensor unit, and thus require staggered sensor units to fill in information for the missing measurement locations.

Figure 6a shows a second possible arrangement of sensor units which is more suitable to sensor unit configurations of Figures 4b and 4c, if this type of system is arranged in the CD. In the arrangement of Figure 6a, the measurement location for each sensor unit is considerably smaller than the width of the sensor unit. Thus, there is some spacing --labeled 60 in Figure 6a-- between each measurement location in a single cross-direction line of sensor units. To collect data from each point along the cross-direction line, a second row of sensor units is added, offset from the first row of sensor units. The second row of sensor units is used to pick up the regions in the cross-direction line missed by the first row of sensor units.

To eliminate any CD/MD coupling, the reading from the second row of sensor units is delayed slightly, so that the same cross-direction line of the sheet is measured with the second row of sensor units as was measured with the first row of sensor units. Figure 6c - 6d show how this is accomplished. By monitoring the speed of the sheet, the designer may determine the time it takes for a cross-direction line, such as the one labeled 61 in Figures 6c - 6e to move a fixed distance. With this information, the designer may determine when the cross-direction line will move from the position

shown in Figure 6c (i.e. t_o) to the position shown in Figure 6d (i.e. t_1), and then from the position shown in Figure 6d to the position shown in Figure 6e (i.e. t_2). Then, by delaying reading of the second row of sensor units a time (t_2 - t_1), points along the same cross-direction line are taken with both rows of sensor units.

As a second reason for staggering sensor readings, they may allow use of slower (any typically more cost effective) radiation detectors. By purposely staggering the sensor units in a configuration similar to that shown in Figure 7a and 7b for example, the radiation detectors in each sensor unit are allowed a marginally larger time to recover from their last reading. Of course, the disadvantage of this type of system is that it uses substantially more space in the sheet forming machine, and as the amount of delay increases from the first to last sensor unit to examine the sheet in any chosen cross-direction line, a larger chance exists that the sheet will bounce or move, thus making early and late readings in one cross direction line more difficult to correlate.

One possible solution to this problem is to average a number of sensor unit readings from one examination of the sheet to the next. This effectively reduces the effect of short term deviations such as movement of the sheet. The averaging technique is suitable, in fact, for any configuration of the sensor units to eliminate selected high frequency problems.

A third possible use for staggered sensor unit readings in the Applicants'' system is shown by the system of Figure 6f. In the figure, a row of sensor units is arranged in the MD. While in previous systems it would have been typical to have each sensor unit measure the same set of wavelengths, in the system shown, each sensor unit measures a different set of frequencies. If staggered reading scheme is applied to this system, the measurement system may use each sensor unit in the system to read data from the same spot as it passes by. Thus, for the example shown in the figure, 14 wavelengths or wavelength bands are collected for the same spot on the sheet.

Another possible embodiment utilizing staggered sensor units (and suitable for MD or CD oriented systems) but which avoids the timing complications of the system of Figures 6a -6e is shown in Figure 8a and 8b. In this arrangement, the sensor units have been tilted somewhat so that the measurement locations for the two rows of sensor units interlace, as is shown in Figure 8a. While this is possible for systems in which scattered radiation is being measured, it may not be suitable for other types of measurements requiring accurate reflected radiation data.

For any of the above described systems, the use of reflective coatings mounted

on the underside of the sensor units can improve the amount, accuracy, or type of information provided by the sensor units. One possible embodiment of this type of system is shown in Figures 9a and 9b. In the figures, a reflective coating 90, such as a layer of quartz coated on one side with aluminum is mounted to the lower face of a row of sensor units. Openings may be provided in the reflective layer for the source of radiation and the radiation detectors, or the layer may be provided without openings.

There are a number of possible advantages to the addition of a reflective layer in the Applicants'' system. One advantage is that the same device may be used for a wider range of sheet types, since the reflective coatings make thick and thin sheet materials appear the same to the radiation detectors.

A second advantage of the reflective coatings is that they may be used to adjust transmissive radiation measurements (i.e. measurements straight through the sheet) using scattered radiation signals. For example, in Figure, 9c, radiation detector 93 receives transmitted radiation from source or radiation 94, while radiation detector 95 receives scattered radiation data from source or radiation 94 via sheet 96. The data from radiation detector 95 may then be used to adjust the transmitted radiation signal produced by radiation detector 93. In actuality, the technique of adjusting the transmitted radiation signal by the scattered signal may be accomplished without the reflective coating, although the reflective coating enhances the result of this technique.

Further advantage of the addition of reflective coatings to the Applicants'' basic invention may be found in the U.S. Patent 3,793,524 to Howarth, and U.S. Patent 5,276,327 to Bossen et al.

As a final addition to the Applicants'' invention, used to account for some variations in measurement location size, the sensor units may be dithered (vibrated back and forth) to cover slightly more surface of the sheet. Dithering may be accomplished physically by vibrating the sensor unit mounting frame, or by vibration of individual sensors. While dithering does add back in a small component of MD/CD coupling to the readings collected from the sensor units, in some circumstances it may be the most preferable option. For example, if a weak signal requires the sensors be very close to the sheet, the measurement locations may not cover the entire surface in the measurement region without the help of the dithering mechanism to slightly increase the area of the web covered by each sensor unit.

One simple method of producing dither would be to mount the sensor units on a sliding shaft which is oscillated back and forth using a cam, such as is shown in Figure

11. In this side view of the dithered system, a slideable bar 100 is mounted to sensor unit arrangement 101, freely moving in guides 102 and 103 is oscillated back and forth by pin 104 mounted near an outer edge of wheel 105. Wheel 105 is attached to the shaft of a motor 106, which rotates the wheel, at for example a period of one second, above sheet 107.

Thus, since the invention disclosed herein may be embodied in other specific forms without departing from the spirit or general characteristics thereof, some of which forms have been indicated, the embodiments described herein are to be considered in all respects illustrative and not restrictive. For example, the Applicants'' has not described in detail systems in which only a portion of the width of the sheet is scanned, although such systems are clearly possible using the Applicants'' described system and techniques. The scope of the invention is to be indicated by the appended claims, rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are intended to be embraced therein.

CLAIMS

1. A non-scanning system for determining characteristics of a moving sheet of material in a measurement region at one or more measurement locations, comprising:

a first sensor unit for determining characteristics of the moving sheet of material at a first of the one or more measurement locations comprising:

a first radiation detector for detecting a first radiation wavelength from the first of the one or more measurement locations; and

a least a second radiation detector for detecting a second radiation wavelength from the first of the one or more measurement locations; and

a least a second sensor unit for determining characteristics of the moving sheet of material at a second of the one or more measurement locations substantially contiguous or over-lapping with the first of the one or more measurement locations, comprising:

a third radiation detector for detecting a third radiation wavelength from the second of the one or more measurement locations; and

a least a fourth radiation detector for detecting a fourth radiation wavelength from the second of the one or more measurement locations.

2. The apparatus of claim 1 wherein said first and third and said second and fourth radiation wavelengths are the same.

3. The apparatus of claim 1 wherein a single source of radiation illuminates the sheet at the measurement region or a section of the measurement region larger than a single measurement location.

4. The apparatus of claim 1 wherein the first and second sensor units further comprise first and second sources of radiation which illuminate the sheet at the first and second measurement locations, respectively.

5. The apparatus of claim 1 wherein:

said first sensor unit further comprise at least a fifth and sixth radiation detectors for

detecting a fifth and sixth radiation wavelengths from the first measurement location, respectively; and

said second sensor unit further comprise at least seventh and eighth radiation detectors for detecting a seventh and eighth radiation wavelengths from the second measurement location, respectively.

6. The apparatus of claim 1 wherein said fifth and seventh and said sixth and eighth radiation wavelengths are the same.

7. The apparatus of claim 5 wherein the radiation detectors are arranged in circumference, around the measurement location.

8. The apparatus of claim 7 wherein said radiation detectors are equally spaced around the measurement location.

9. The apparatus of claim 8 wherein the first and second sources of radiation lie directly adjacent the first and second measurement locations respectively, and at the center of the radiation detectors.

10. The apparatus of claim 8 wherein the first and second sources of radiation lie on the opposite side of the sheet from the radiation detecctors.

11. The apparatus of claim 1 wherein a sufficient number of sensor units are used to measure the sheet at every point across the sheet in the CD.

12. The apparatus of claim 1 wherein the sensor units are arranged in parallel across the sheet in the CD, and take measurements simultaneously.

13. The apparatus of claim 1 wherein the sensor units are staggered, and take measurements in a sequence so that all sensor units components measure along the same cross-direction line.

14. The apparatus of claim 1 in which a reflective coating is applied to the surface of the sensor unit adjacent the sheet, whereby multiple reflections from the sheet may

occur before radiation from the source of radiation reaches the radiation detector.

15. The apparatus of claim 1 in which the measurement location for one or more sensor unit is dithered to change the location of the measurement location in the cross-direction strip.

16. The apparatus of claim 15 wherein the dithered sensor unit examines more measurement locations across the sheet than accomplished if the sensor units are not dithered.

17. The apparatus of claim 1 wherein the sensor units are arranged in parallel across the sheet in the MD, and take measurements simultaneously.

18. The apparatus of claim 1 wherein the sensor units are arranged in parallel across the sheet in the MD, and take measurements non-simultaneously, wherein the delay between measurement by one sensor unit and the next causes all sensor units to measure from the same spot on the sheet.

19. The apparatus of claim 1 wherein the first and second measurement locations are the same spot on the sheet.

20. An apparatus for non-scanning measurement of a sheet of moving material comprising:

a plurality of sensor units each comprising:

a plurality of radiation detectors, each detector detecting a different radiation wavelength band from a measurement location on the sheet, each of the plurality of sensor units directed at a different measurement location in a substantially continuous line across the sheet; and

a source of radiation lying adjacent the radiation detectors, the source of radiation directing radiation at the measurement location for the associated radiation detectors.

21. The apparatus of claim 20 wherein the line across the sheet is in the MD direction.

22. The apparatus of claim 20 wherein the line across the sheet is in the CD direction.

23. The apparatus of claim 20 wherein not all of the radiation detectors lie on the same side of the sheet.

24. An apparatus for non-scanning measurement of a sheet of moving material comprising:

a plurality of sensor units each comprising:

a plurality of radiation detectors, arranged in an MD line, each detector detecting a different radiation wavelength band from a measurement location on the sheet, all of the sensor units directed at a common measurement location; and

a source of radiation lying adjacent the radiation detectors, the source of radiation directing radiation at the measurement location for the associated radiation detectors.

25. An apparatus for non-scanning measurement of a sheet of moving material comprising:

a plurality of sensor units each comprising:

a plurality of radiation detectors, arranged in an MD line, each detector detecting a different radiation wavelength band from a measurement location on the sheet, all of the sensor units directed at a common measurement location; and

a source of radiation lying one the opposite side of the sheet from the radiation detectors, the source of radiation directing radiation at the measurement location for the associated radiation detectors.

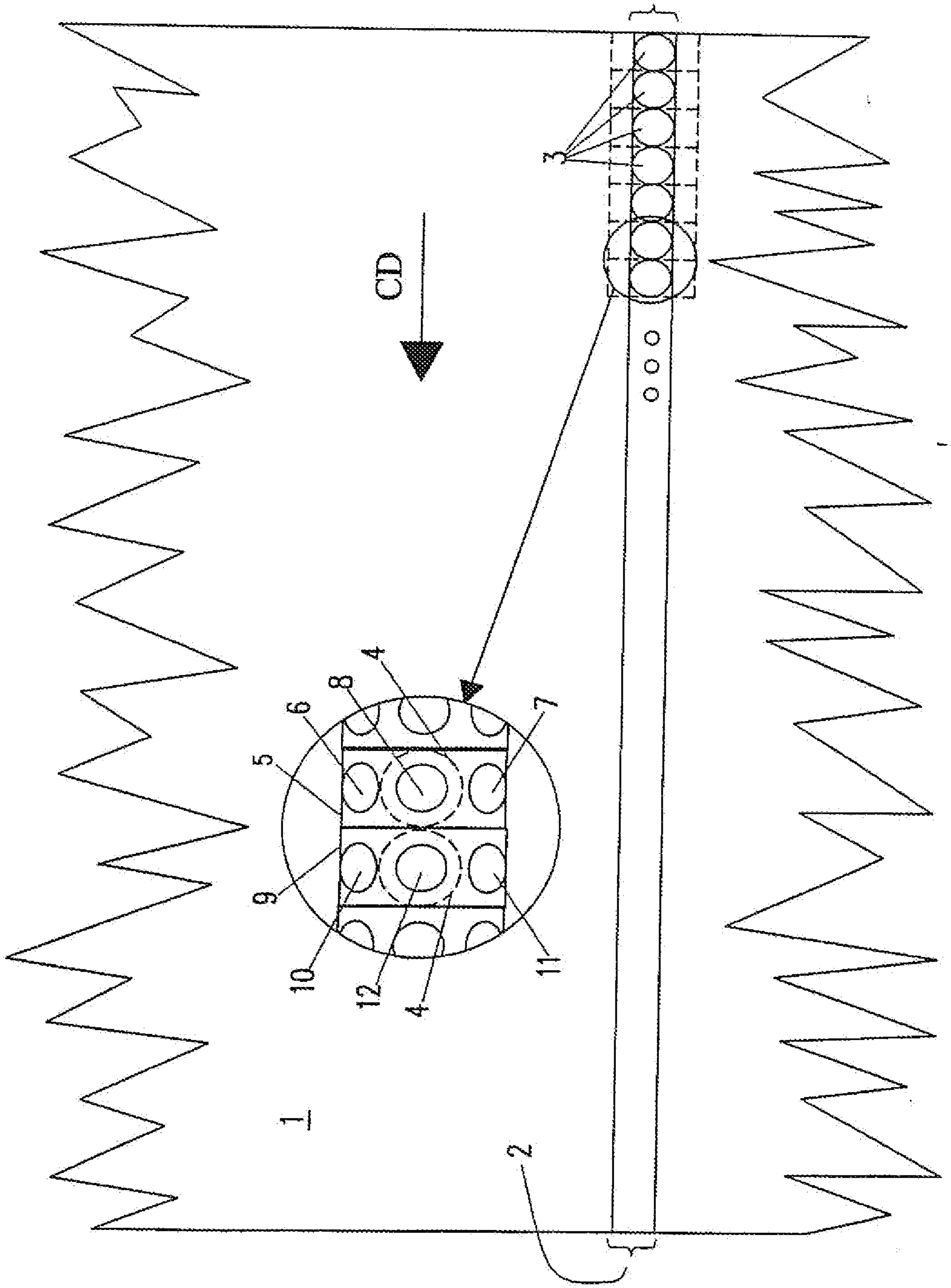

Fig. 1a

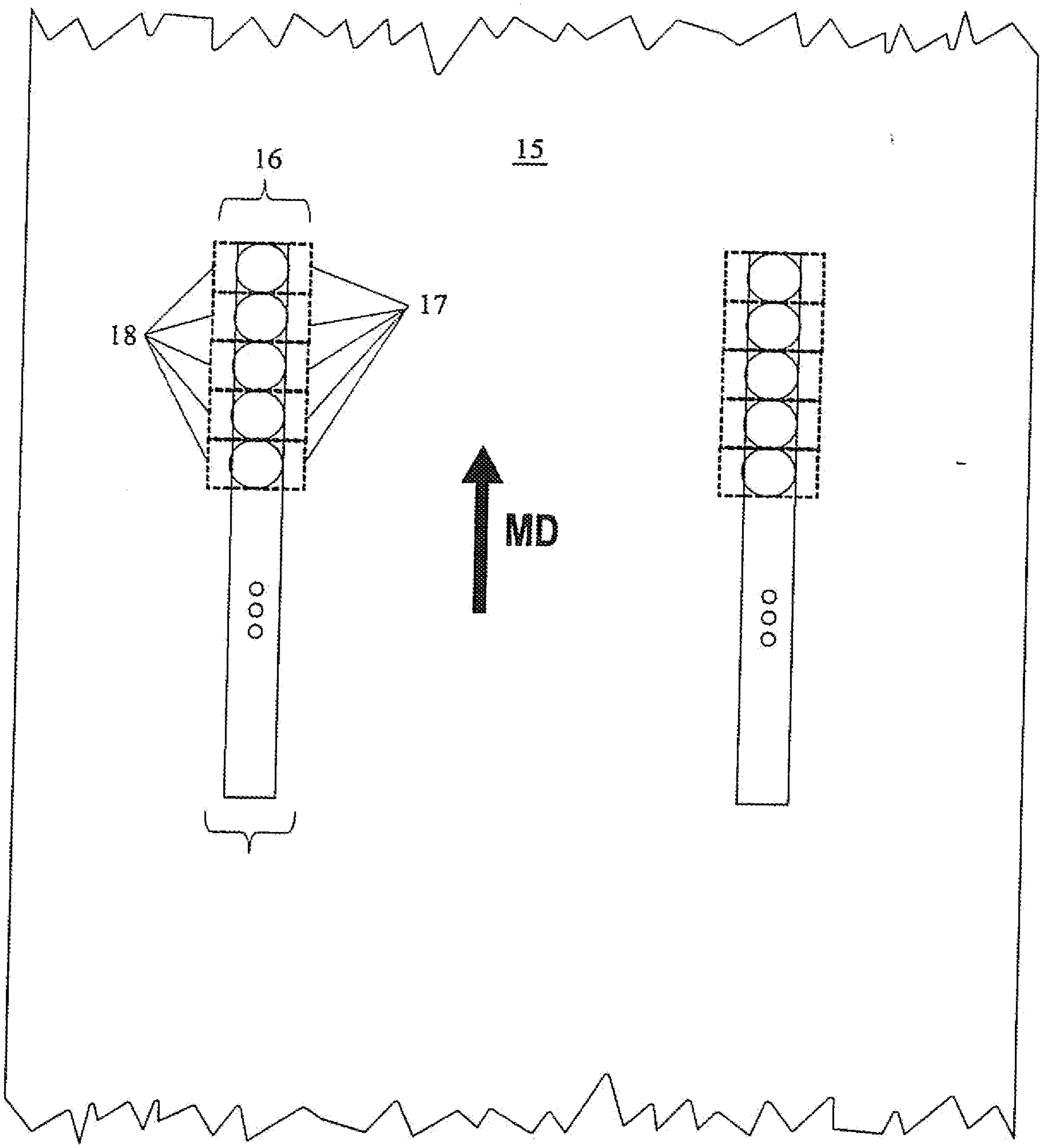

Fig. 1b

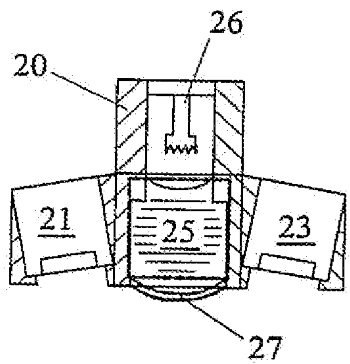

Fig.2a

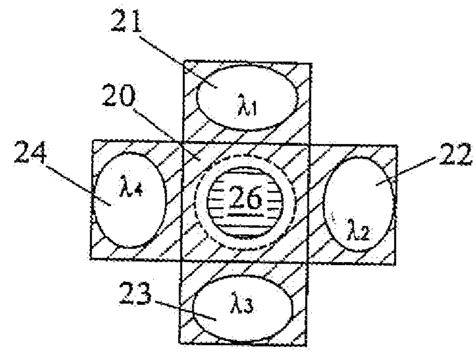

Fig.2b

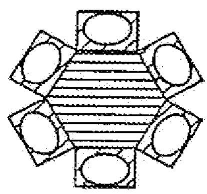

Fig.2c

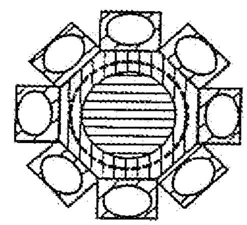

Fig.2d

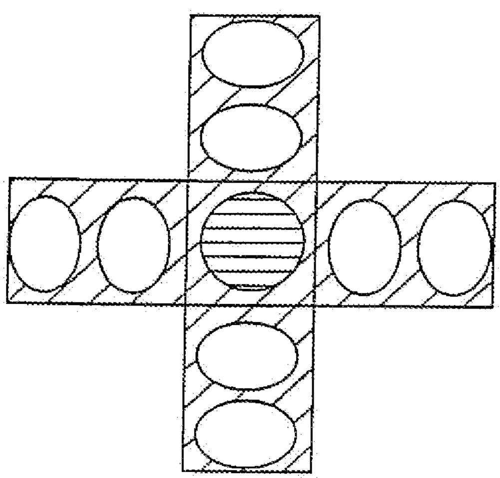

Fig.2e

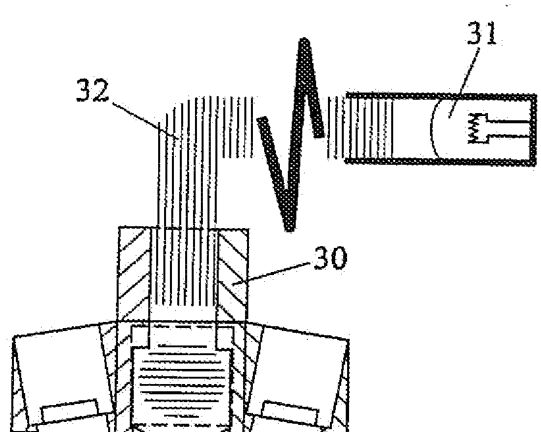

Fig.3

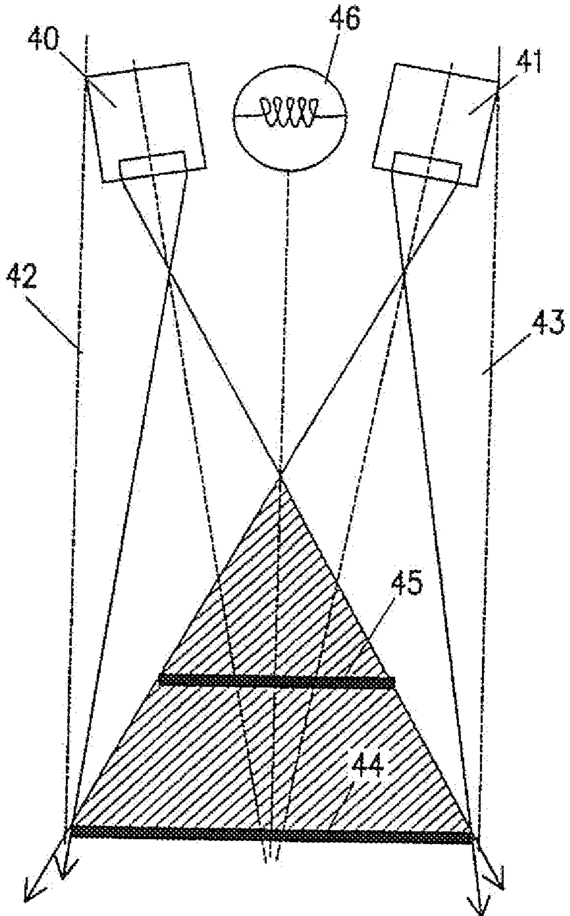

Fig.4a

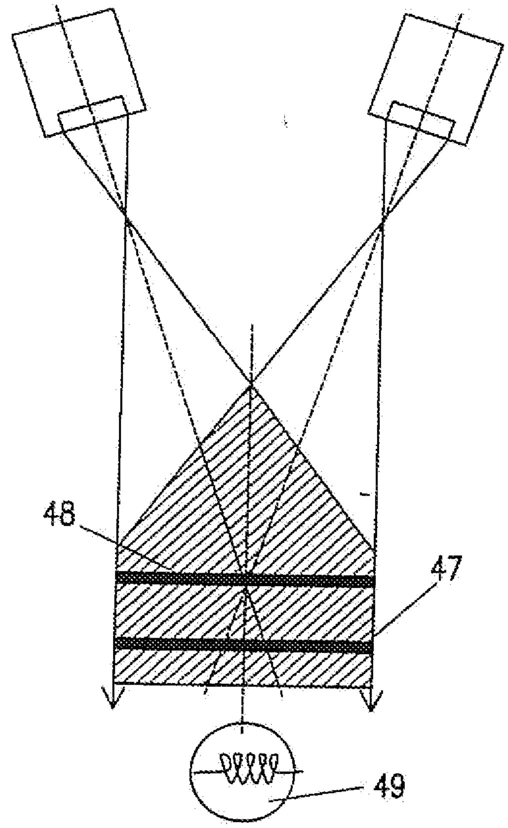

Fig.4b

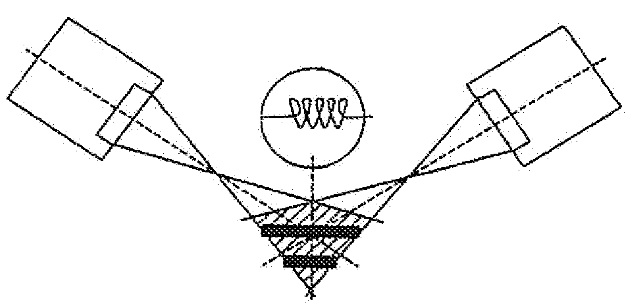

Fig.4c

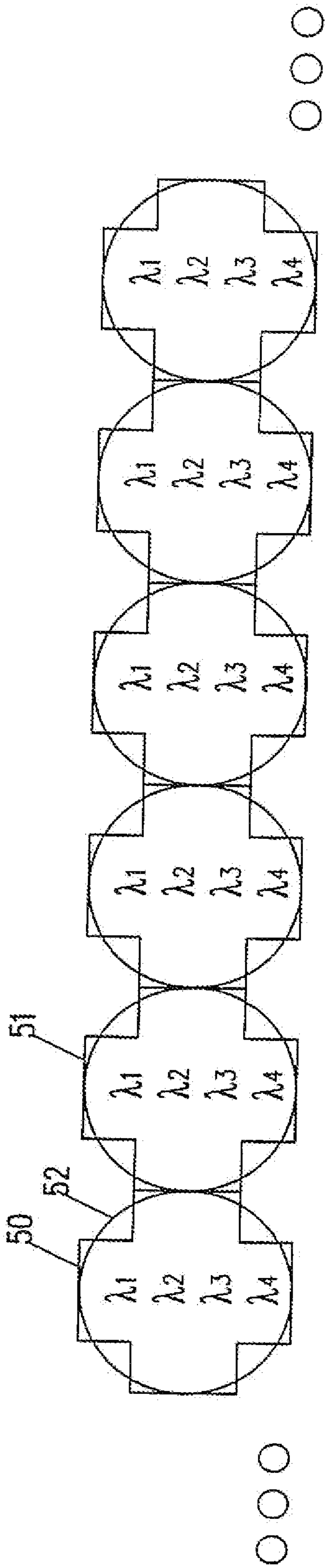

Fig.5a

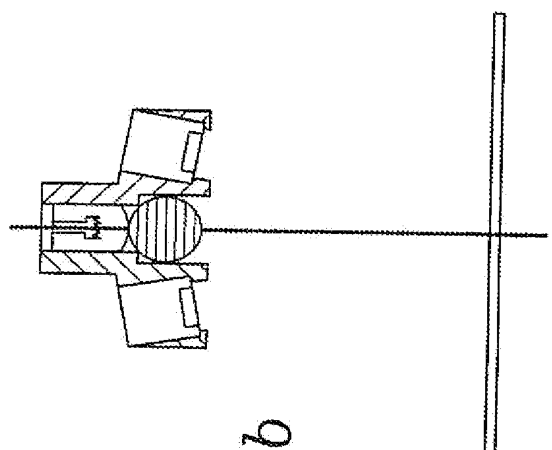

Fig.5b

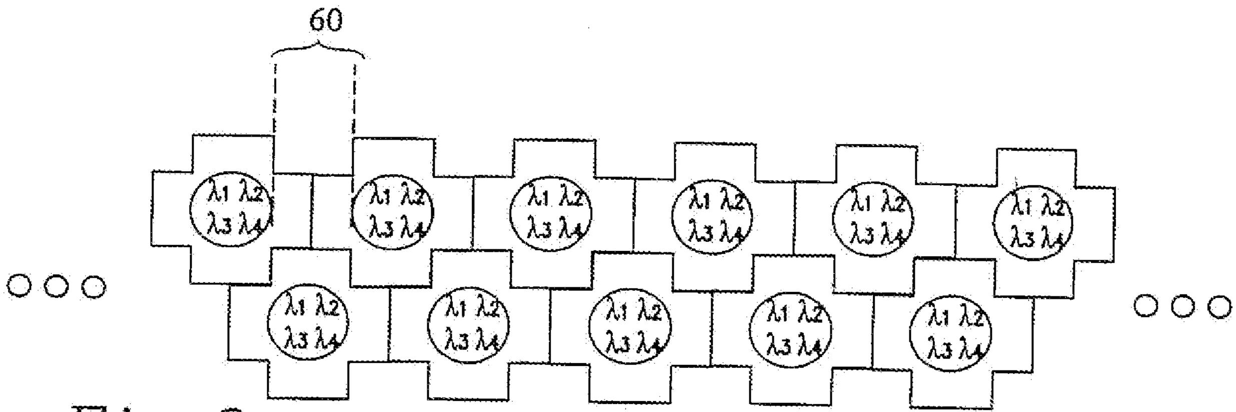

Fig.6a

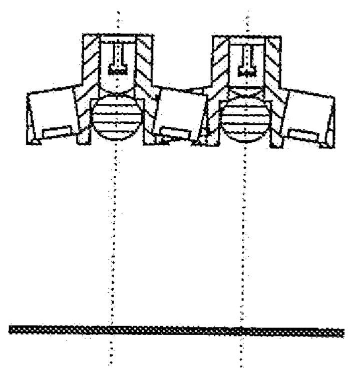

Fig.6b

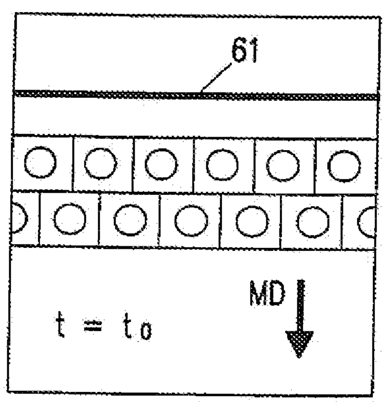

Fig.6c

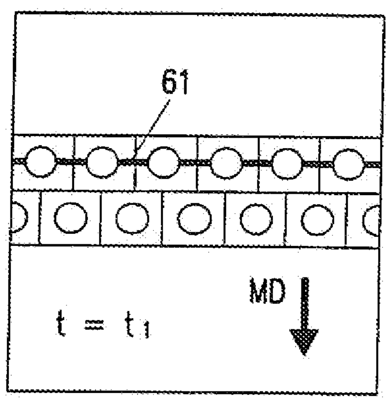

Fig.6d

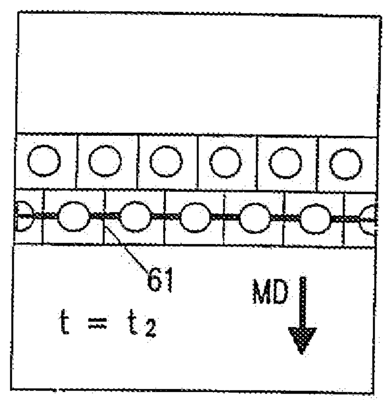

Fig.6e

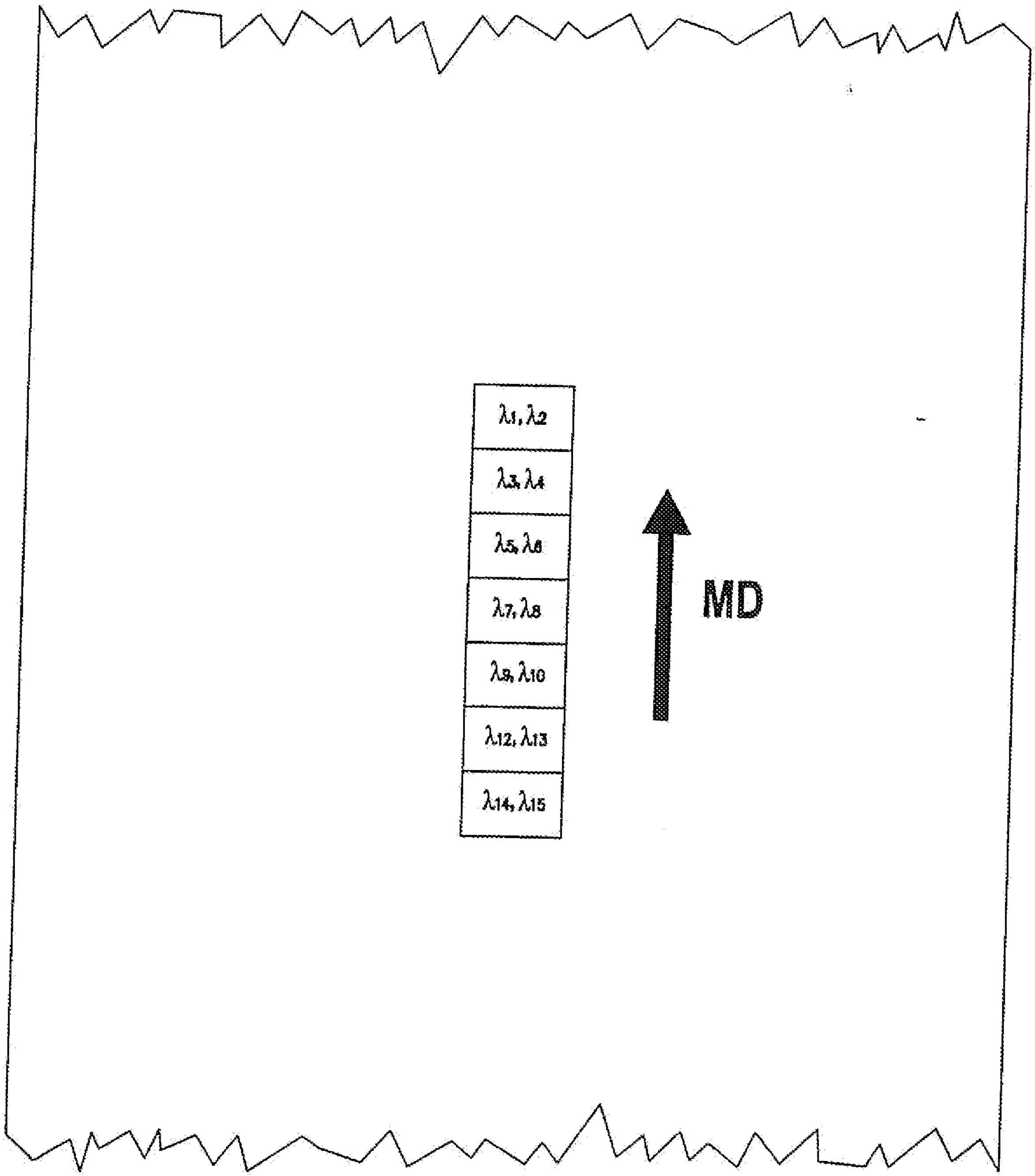

Fig. 6f

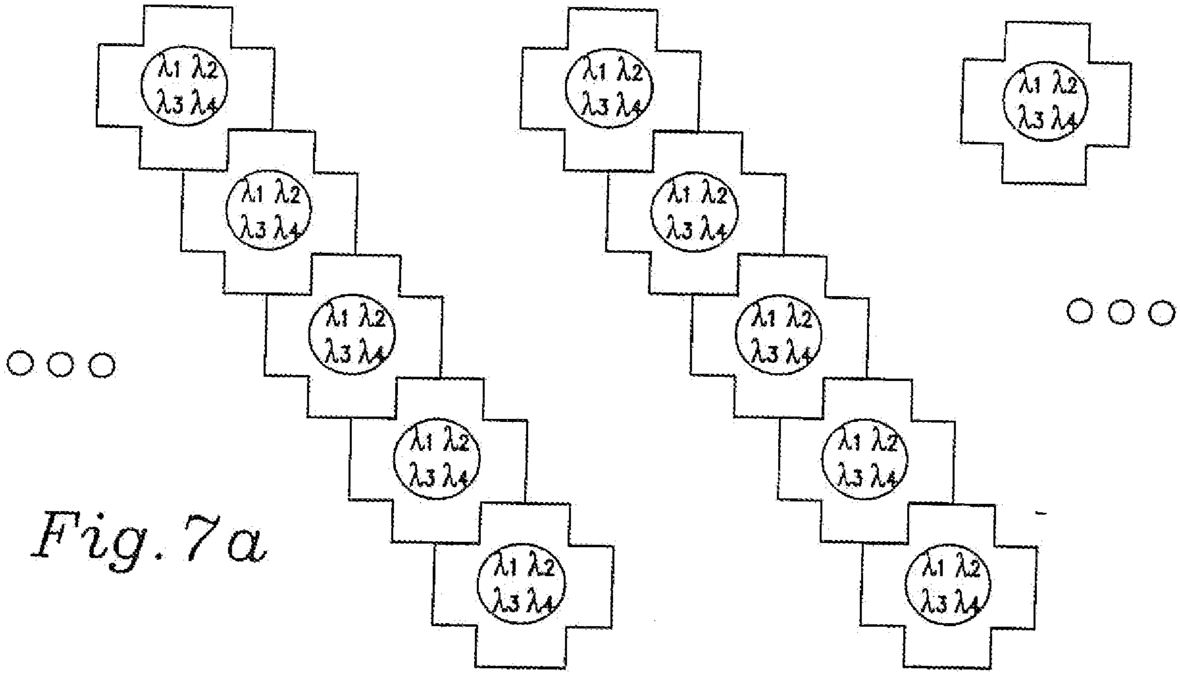

Fig.7a

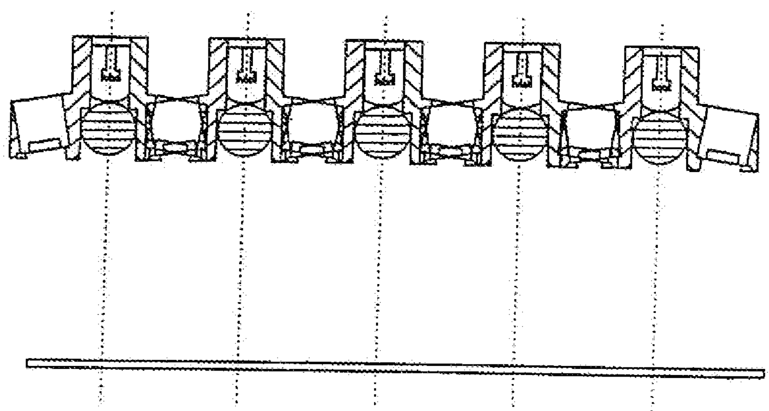

Fig.7b

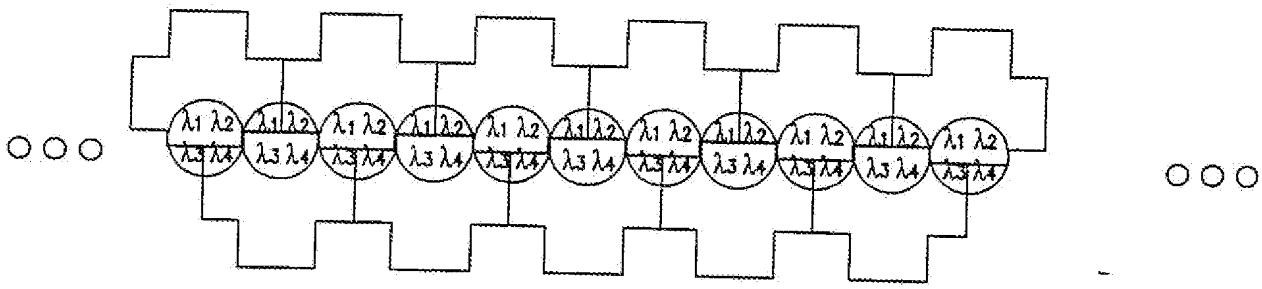

Fig. 8a

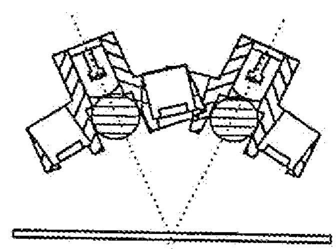

Fig. 8b

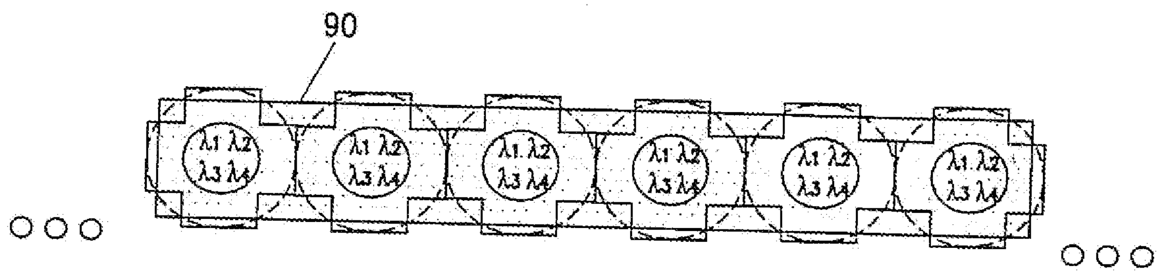

Fig. 9a

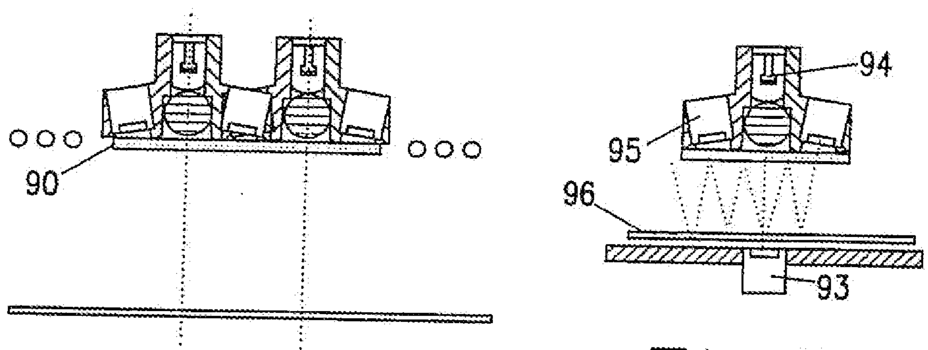

Fig. 9b

Fig. 9c

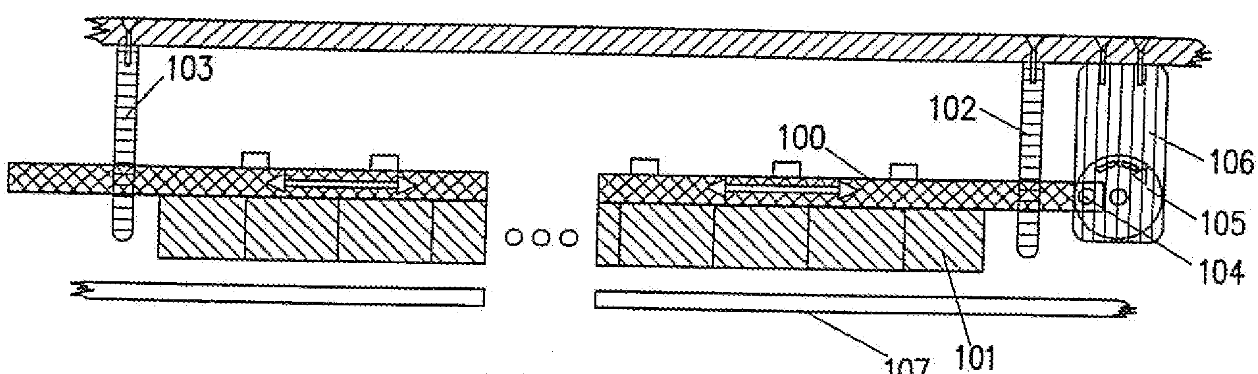

Fig. 10

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/27260

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01N21/89

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	EP 0 258 150 A (MEASUREX CORP) 2 March 1988 (1988-03-02) page 2, line 54 -page 3, line 5 page 4, line 19 - line 30 page 4, line 59 -page 5, line 6 figures 2,7	1-3,5,6, 11,12, 20,22 7,13,14, 23 24,25
Y	GUESALAGA A R ET AL: "ON LINE MEASUREMENT OF QUALITY VARIABLES IN PAPER: FORMATION AND CREPING" PROCEEDINGS OF THE REGION TEN CONFERENCE (TENCON),CN,BEIJING, IAP, vol. -, 1993, pages 366-369, XP000451748 figure 1	7

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 March 2000	03/04/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Navas Montero, E

3

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

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